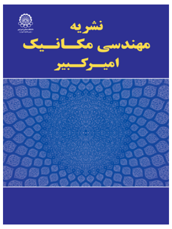

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 53(Special Issue 5) (2021) 787-790
DOI:10.22060/mej.2020.18086.6729

Numerical investigation of compartment fire under maximum and minimum of natural ventilation using flamelet generated manifold combustion model

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ABSTRACT: When the fire in the room reaches a critical state, the fire can create hazards for the upper floors. In this paper, different fire cases with more and less natural ventilation than the critical state are discussed, and the temperature, velocity, and toxic species are discussed. A two-floor building is simulated using a large eddy simulation and PIMPLE algorithm and how the fire spreads upstairs is examined. Fuel flow rates are considered at three heat release rates of 500, 1000 and 5000 kW. The flamelet-generated-manifold combustion model is used to analyze toxic species and the results are compared with the experimental results. The relative error is less than 15%. With increasing fuel heat release rates, the upper floor is more exposed to fire hazards such that if the heat release rate is 500 kW, the temperature in the second floor reaches 390 K and the CO species reaches 25 ppm. But if the heat release rate is below 1000 kW, the upper floor will not be at particular risk. Generally, the level of diffusion of CO2 into the second floor is lower than the toxicity level for humans (25-50 ppm) and the second floor is not endangered for CO2 gases.

Review History:

Received: Mar. 18, 2020
Revised: Jun. 30, 2020
Accepted :Aug. 31, 2020
Available Online: Sep. 08, 2020

Keywords:

Compartment fire
Large eddy simulation
Natural ventilation
Flamelet generated manifold combustion model.

1- Introduction

Investigating a fire in a room is one of the most important fire scenarios in a building, which is much more complex than a fire in an open space; This is because the fire is trapped in the room and the rate of release of combustible fuel varies according to the ventilation of the room and the result of heat transfer inside the room. This can trap flammable gases in the room for a while and suddenly release it and cause an explosion [1]. When the room temperature reaches a certain level, flammable gases (from a fire or the release of gases such as methane) begin to burn inside the room. With the ignition of gases inside the room, a flashing phenomenon occurs when the gases are expelled from the room and a volume of unexploded gases is transferred out of the room and ignited outside the room. This phenomenon can create hazards for the surrounding environment, including the upper floors [2] and other rooms of a building [3, 4]; therefore, the study of fire in the room at different heat release rates can partially reveal this phenomenon to prevent its occurrence [5, 6].

However, accurate information on different fire scenarios can be obtained using experimental study; but the details of the temperature field, velocity and dangerous species cannot be easily known in experimental study. Therefore, numerical studies can be used as a tool to study the details of different fire scenarios. One of the concerns of combustion simulation is the use of a model with a suitable computational time as well as high accuracy in simulation of fire, which is one of the gaps in previous studies.

In this study, a two-floor building is investigated using a large eddy simulation method and the Flamelet Generated Manifold (FGM) combustion model, which is a complete combustion model that predicts the exact details of fire-hazardous species. The first floor is the fire room and the second floor is exposed to the combustion gases of the first floor. In order to investigate the hazards status that may occur for the second floor, the temperature field and toxic species on the second floor are examined and compared with the critical values of international standards [7]. Also, in order to comprehensive the results, the rate of heat release in the fire room in different modes of maximum and minimum natural ventilation is examined.

2- Governing Equations

Using the Favre filtering method, can filter the equations of reactive flow such as continuity, momentum, energy and species transport equation. one equation Sub-Grid Scale (SGS) model [8] for sub-grid stress and FGM combustion model was used with GRI reaction mechanism, and the radiation model of the discrete-ordinate approach was used for radiation modeling [9].

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3- Numerical Method

In the present modeling, the fireFoam solver has been used; in the fireFoam solver, the equations are implicitly applied in the program. The value of the local Courant number is considered to be 0.4. For all convective terms in flow equations, turbulent kinetics energy, energy transfer, the transfer of mixture fraction, the second-order scheme has been used.

The verification of the results in the one-room space scenario is performed based on Steckler's experimental results [10]. The fuel used is methane.

A heat release rate of 64 kW is used to verify the results; however, to investigate the effect of heat release rate on fire behavior in a two-floor building, the heat release rate of 500, 1000 and 5000 kW, which are equivalent to less and more than the critical condition of natural ventilation according to the relationship presented by Sun et al. [11], are applied.

In order to investigate the fire behavior in a two-floor building under natural ventilation at different heat release rates, two-room space on two floors are considered according to Fig. 1. This geometry consists of two rooms with experimental geometry characteristics of [10]. In the first floor, the fire can be exited through a door with dimensions of 74 × 180 cm^2, and in the second floor, a window with dimensions of 76 × 83 cm^2 has been installed, which is in the path of the fire, and the fire can enter the second floor through the window.

4- Discussion and Results

Over time, the temperature on the second floor is increased by the exhaust gases from the first floor. At 10 seconds, the temperature near the roof of the second floor reaches about 330 K and the temperature gradually increases until at 40 seconds the temperature on the second floor reaches 380-390 K and approaches the critical temperature range. Therefore, it can be seen that in a situation where the heat release rate is 5000 kW, fire in the building can be dangerous for the upper floors.

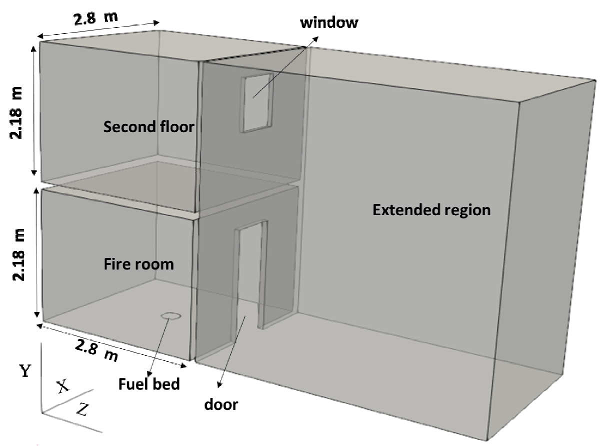

Fig. 1. test case of two-floor building

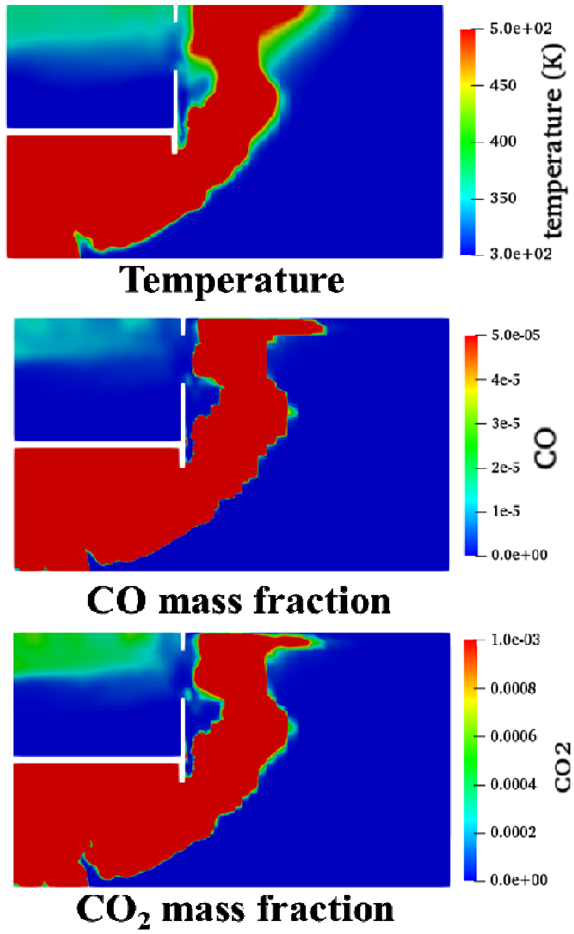

Fig. 2. Temperature field and toxic gases for a heat release rate of 5000 kW at 40s

5- Conclusions

It was observed that when the heat release rate is less than 1000 kW -when natural ventilation is in critical and over-ventilation-, there is no serious problem for the second floor in terms of temperature and toxic species; but in the case of under-ventilation, the second floor is at risk. As carbon monoxide and temperature reach a critical state. For example, when the heat release rate is less than 5,000 kW, the temperature on the second floor reaches 420 K and the toxic carbon monoxide reaches 76 ppm, which is higher than the allowable level for damage. Another important point is that the toxic species of carbon dioxide on the second floor has not reached a critical state for any of the heat release rates.

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HOW TO CITE THIS ARTICLE

M. Safarzadeh, Gh. Heidarinejad, H. Pasdarshahri., . Numerical investigation of compartment fire under maximum and minimum of natural ventilation using flamelet generated manifold combustion model ,*Amirkabir J. Mech. Eng., 53(Special Issue 5) (2021) 787-790*

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